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This article reviews causes of marathon collapse related to physical exhaustion, heat exhaustion and dehydration. During severe exercise-heat stress (high skin and core temperatures), cardiac output can decrease below levels observed during exercise in temperate conditions. This reduced cardiac output and vasodilated skin and muscle can make it difficult to sustain blood pressure and perhaps cerebral blood flow. Dehydration can accentuate this cardiovascular strain. In contrast, excessive heat loss to the environment during cold weather may result in hypothermic collapse. Other factors contributing to post-race collapse might include reduced skeletal muscle pump activity and dehydration and prior heat stress mediated changes in cerebrovascular responses to orthostatic challenges.

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Heat Exhaustion and Dehydration as Causes of Marathon Collapse

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Abstract

This article reviews causes of marathon collapse related to physical exhaustion, heat exhaustion and dehydration. During severe exercise-heat stress (high skin and core temperatures), cardiac output can decrease below levels observed during exercise in temperate conditions. This reduced cardiac output and vasodilated skin and muscle can make it difficult to sustain blood pressure and perhaps cerebral blood flow. Dehydration can accentuate this cardiovascular strain. In contrast, excessive heat loss to the environment during cold weather may result in hypothermic collapse. Other factors contributing to post-race collapse might include reduced skeletal muscle pump activity and dehydration and prior heat stress mediated changes in cerebrovascular responses to orthostatic challenges.

Marathon running is a reasonably safe endeavor with only one reported death per 50 000 participants.[1] Despite this relatively low rate of catastrophic injury, physical collapse during the marathon can occur either during the race itself or immediately following completion of the event. Roberts[2] has reported an exercise-associated collapse incidence rate of 1.13% of race entrants over 12 Twin Cities Marathon races and rates of collapse of 0.2–3.7% have been reported for other distance running events.[3] Collapse during the marathon may be caused by any number of factors, including cardiac arrest, hypoglycaemia, hyponatraemia, dehydration, hyperthermia and hypothermia. Collapse following the event is typically caused by postural hypotension, a result of the cessation of exercise and/or heat strain and/or dehydration. Although various pathologies or other medical conditions may lead to collapse, the purpose of this review is to provide an overview of causes of marathon collapse related to exhaustion, heat exhaustion and dehydration.

1. Physical Exhaustion

Exhaustion during marathon competition may be the result of several factors, individually or in combination. Factors related to collapse from exhaustion during the event may include hypoglycaemia, from inadequate carbohydrate intake, insufficient training for the event or use of a strategy during the race for which runners were not properly trained. As noted by Roberts[2] and Holtzhausen et al.,[3] there is an increase in the rate of collapse at ≈3.5 hours after the start of the race, likely among runners attempting to achieve qualifying times for other marathons. Their intense efforts may be greater than the current fitness level or heat acclimatisation status of the athlete and may further result in either glycogen depletion or hyperthermia. Any of these factors, alone or in combination, may contribute to collapse.

2. Hyperthermia and Dehydration

During exercise-heat stress, the primary mechanisms for heat loss are increased skin blood flow and sweat secretion. Maintaining high skin blood flow

can impose a substantial burden on the cardiovascular system. High skin blood flow is associated with reduced cardiac filling, reduced right atrial pressure and reduced stroke volume, which require a higher heart rate to maintain cardiac output. This reduction in cardiac filling occurs because the cutaneous venous bed is large and compliant, and dilates during heat stress. In addition, sweat secretion can result in a net body water loss (dehydration), thereby reducing blood volume. Therefore, heat stress can reduce cardiac filling both through pooling of blood in the skin and through reduced blood volume. During severe exercise-heat stress (high skin and core temperatures), cardiac output can decrease below levels observed during exercise in temperate conditions. This reduced cardiac output and vasodilated skin and muscle can make it difficult to sustain blood pressure and perhaps cerebral blood flow.[4]

3. Exhaustion from Heat Strain

Core temperature and skin temperatures provide indices to predict the incidence rate for exhaustion from heat strain.[5] Figure 1 illustrates some relationships between core temperature and incidence of exhaustion from heat strain for heat-acclimated persons exercising in uncompensable (most likely very hot skin) and compensable (most likely cool skin) heat stress. During compensable heat stress, exhaustion is almost always seen at core temperatures >39°C. During uncompensable heat stress, exhaustion is often associated with a core temperature <39°C, and exhaustion will almost always occur by a core temperature of 40°C. A higher skin temperature (>35°C, as seen during uncompensable heat stress) will be associated with greater cardiovascular strain for a given core temperature and therefore result in earlier exhaustion. If the skin is relatively cool, then higher core temperatures can be better sustained during exercise due to reduced skin blood flow requirements. Dehydration will not only increase core temperature, but can cause exhaustion to occur at a lower core temperature.[5]

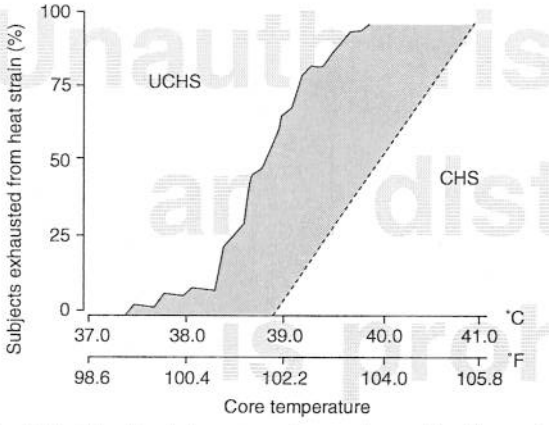

Fig. 1. Relationships between core temperature and incidence of exhaustion from heat strain for heat-acclimated persons exercising in uncompensable (hot skin) and compensable (cool skin) heat stress. During uncompensable heat stress (UCHS), evaporative heat loss is insufficient to dissipate body heat and skin temperatures are relatively high. During compensable heat stress (CHS), heat loss is sufficient to dissipate body heat and skin temperatures are relatively low.

In the marathon and ultramarathon distances,[6] core temperatures in runners who have collapsed during or after the race were reported to be between 38 and 40°C. This suggests that skin temperatures may have been high and perhaps in combination with some degree of dehydration. Despite the relatively low body core temperatures in collapsed runners, environment does appear to play a role in collapse. It is also important to note that there may be a time period between the collapse of the athlete and the measurement of body core temperature. During this period of time individuals are exposed to varying environments and may gain or lose heat to the environment, thus changing body core temperature from that at the time of collapse. Using a linear regression model, which included collapse due to dehydration, vasovagal syncope, orthostatic syncope, exhaustion and hyperthermia, Roberts[2] reported a general trend towards increased collapse rate with higher dew points. If evaporation is limited as a result of high dew-point temperature or running in a pack where evaporative heat loss can be reduced as a result of lower air flow, skin temperatures would become elevated.

If skin temperature is low, some runners can tolerate remarkably high core temperatures. Core temperatures ranging from 38.0–41.1°C in runners successfully completing half-marathon and mara-

thon distances[7] have been observed. Pugh et al.[7] reported a core temperature of 41.1°C for the winner of a marathon run and suggested that tolerance of a high body temperature was necessary for success in the marathon. Maron et al.[8] reported one marathon runner maintained a core temperature between 41.6 and 41.9°C for the last 44 minutes of a race when skin temperatures were 24°C.

4. Hypothermia

It is not surprising that during warm weather marathon events there is a greater incidence of collapse as a result of hyperthermia; however, hypothermia (rectal temperature ≤35°C) has often been reported during marathons held in cool and compensable environments. A 12-year profile of exercise-associated collapse casualties for the Twin Cities Marathon reported 3% of the male and 3% of the females runners were classified as hypothermic.[2] In general, runners competing at or below 12°C or in cool, wet weather may be at a greater risk of hypothermia.[9] However, Maughan[9] has reported rectal temperatures classified as hypothermic (35.6°C) to hyperthermic (39.8°C) among runners during the same race, in cool conditions (10–12°C). In addition, Roberts[2] has observed a rectal temperature of 33°C during one of the 'hottest' (16°C) Twin Cities Marathons in 1983. Incidences of hypothermia in various environments during marathon competition may be due to a number of factors. Inexperienced runners may start the race at a pace that is too fast, slowing down or even walking as a result of fatigue later in the event, while being exposed to cool and/or wet weather. As a result, there will be a decline in exercise intensity and heat loss to the environment can exceed heat production leading to declines in core temperature.[4]

Environmental conditions can also change throughout the day of the event, air temperature changes of up to 17°C have been reported[10] and rain, sleet, wind or cloud cover, which may occur later in the event, would have a greater impact on slower runners who are likely to be on the course for a longer period of time. Risk for hypothermia may be further exacerbated by insufficient clothing, as clothing worn at the start of the race may not be appropriate for changes in weather conditions occurring later in day.

5. Postural Hypotension

The most commonly encountered collapse associated with the marathon is postural hypotension, which typically occurs following the event or could occur if an athlete were to stop running for a period of time during the race. Athletes who finish the marathon and collapse are typically fully conscious but are unable to stand without support. This type of collapse is likely due to one factor or a combination of factors. One factor contributing to this hypotension is the large fall in total peripheral resistance which occurs upon the cessation of exercise, where there is a large fall in central blood volume and atrial filling pressure due to the pooling of blood in the dilated capacitance veins of the lower limbs (no muscle pump and dilated skin). In addition, the ability to withstand an orthostatic challenge may be compromised by the combination of heat stress and dehydration. Recent findings[4] have demonstrated that hypohydration and prior heat stress lower cerebral blood flow velocity, which may contribute to syncope observed upon completion of marathon competition.

6. Conclusion

Physical collapse by marathon participants can be related to a number of factors including exhaustion, hypoglycaemia, hyperthermia, hypothermia, dehydration and hyponatraemia. This collapse may be mediated by insufficient training or heat acclimatisation, inappropriate race strategy or inappropriate nutritional (water, electrolytes, carbohydrate) replacement. Collapse due to hyperthermia and dehydration may be the result of cardiovascular strain and an inability to sustain blood pressure. In addition, inadequate evaporative cooling will increase skin temperatures, thus augmenting cardiovascular strain. Excessive heat loss to the environment during cold-wet weather may result in hypothermic collapse. Lastly, collapse related to postural hypotension, occurring after the race, may be the result of

venous pooling in the periphery or alterations in cerebral blood flow velocity from hyperthermia and/or dehydration.

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